

# LEPTOQUARKS AND CONTACT INTERACTIONS FROM A GLOBAL ANALYSIS

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Data from HERA, LEP and the Tevatron, as well as from low energy experiments are used to constrain the scale of possible electron-quark contact interactions. Some models are found to describe the existing experimental data much better than the Standard Model. The possibility of scalar or vector leptoquark contribution is studied using the Buchmüller-Rückl-Wyler effective model. Increase in the global probability observed for scenarios including  $S_1$  or  $\tilde{V}_0$  leptoquark production/exchange corresponds to more than a  $3\sigma$  effect. Assuming that a real leptoquark signal is observed, calculated is an allowed region in the  $\lambda - M$  plane.

## 1 Introduction

In the global contact interaction analysis presented last year<sup>1,2</sup> data from both collider and low energy experiments were used to constrain the mass scale of the possible new electron-quark contact interactions. No indication for possible deviations from the Standard Model predictions was found at that time.

Presented in this paper are results from the updated analysis, which includes new experimental data. Most important are the new results from the atomic parity violation (APV) measurements in cesium.<sup>3</sup> After the theoretical uncertainties have been significantly reduced, the measured value of the cesium weak charge is now  $2.5\sigma$  away from the Standard Model prediction. Also the new hadronic cross-section measurements at LEP2, for  $\sqrt{s}=192-202$  GeV, are on average about 2.5% above the predictions.<sup>4</sup> This is only about  $2.3\sigma$  effect, but has an important influence on the analysis.

## 2 Contact Interactions

Four-fermion contact interactions are an effective theory, which allows us to describe, in the most general way, possible low energy effects coming from “new physics” at much higher energy scales. Vector  $eeqq$  contact interactions can be represented as an additional term in the Standard Model Lagrangian:

$$L_{CI} = \sum_{i,j=L,R} \eta_{ij}^{eq} (\bar{e}_i \gamma^\mu e_i) (\bar{q}_j \gamma_\mu q_j)$$

Table 1: Mass scale limits for different contact interaction models.

| Coupling         | 95% CL exclusion limit $TeV$ |             |             |             |                      |             |             |             |
|------------------|------------------------------|-------------|-------------|-------------|----------------------|-------------|-------------|-------------|
|                  | General approach             |             |             |             | One-parameter models |             |             |             |
|                  | 1 <sup>st</sup> gen.         |             | 3 gen.      |             | 1 <sup>st</sup> gen. |             | 3 gen.      |             |
|                  | $\Lambda^-$                  | $\Lambda^+$ | $\Lambda^-$ | $\Lambda^+$ | $\Lambda^-$          | $\Lambda^+$ | $\Lambda^-$ | $\Lambda^+$ |
| $\eta_{LL}^{ed}$ | 5.3                          | 4.4         | 6.7         | 7.2         | 28.6                 | 8.4         | 30.5        | 8.9         |
| $\eta_{LR}^{ed}$ | 2.4                          | 3.0         | 3.6         | 3.8         | 19.2                 | 7.6         | 19.5        | 7.5         |
| $\eta_{RL}^{ed}$ | 3.5                          | 3.7         | 4.3         | 4.2         |                      |             |             |             |
| $\eta_{RR}^{ed}$ | 2.8                          | 3.5         | 4.0         | 5.9         | 8.0                  | 18.1        | 8.8         | 17.4        |
| $\eta_{LL}^{eu}$ | 4.9                          | 4.6         | 6.0         | 8.2         | 12.5                 | 18.7        | 11.8        | 21.4        |
| $\eta_{LR}^{eu}$ | 4.3                          | 3.4         | 5.0         | 4.8         | 17.4                 | 7.5         | 17.3        | 7.8         |
| $\eta_{RL}^{eu}$ | 3.5                          | 3.7         | 4.3         | 4.2         |                      |             |             |             |
| $\eta_{RR}^{eu}$ | 4.0                          | 3.8         | 4.9         | 4.7         | 6.9                  | 19.7        | 7.0         | 21.2        |
| $VV$             |                              |             |             |             | 6.5                  | 11.1        | 8.2         | 15.1        |
| $AA$             |                              |             |             |             | 5.7                  | 6.3         | 10.5        | 11.7        |
| $VA$             |                              |             |             |             | 4.5                  | 4.6         | 5.7         | 7.8         |

where the sum runs over electron and quark helicities. Couplings  $\eta_{ij}^{eq}$  describing the helicity and flavor structure of contact interactions can be related to the effective mass scale  $\Lambda$ :  $\eta = \pm 4\pi/\Lambda^2$ .

In the presented analysis different CI scenarios are considered. The so called first-generation models assume that contact interactions couple only electrons to  $u$  and  $d$  quarks. In the three-generation model lepton universality ( $e=\mu$ ) and quark family universality ( $u=c=t$  and  $d=s=b$ ) is assumed. Assuming  $SU(2)_L \times U(1)_Y$  gauge invariance, there are 7 independent couplings ( $\eta_{RL}^{eu}=\eta_{RL}^{ed}$ ). In the most general approach different couplings are allowed to vary independently, whereas in the so called one-parameter scenarios only one coupling (or given combination of couplings<sup>1</sup>) is allowed to be non-zero.

The analysis combines relevant data from HERA, Tevatron and LEP2, results from low-energy  $eN$ ,  $\mu N$  and  $\nu N$  scattering experiments, constraints on the CKM matrix unitarity and electron-muon universality, and the atomic parity violation (APV) measurements.<sup>5</sup>

The best description of all data is obtained for three-generation model with  $e_L d_L$  type coupling. Increase in the global probability  $\mathcal{P}(\eta)$  corresponds to  $3.8\sigma$  deviation from the Standard Model. The mass scale of new interaction is  $\Lambda_{LL}^{ed} = 13.2 \pm 1.8$  TeV ( $10.3$  TeV  $< \Lambda_{LL}^{ed} < 21.9$  TeV on 95% CL).

95% CL exclusion limits on  $\eta$  are defined as minimum ( $\eta^-$ ) and maximum ( $\eta^+$ ) coupling values resulting in the global probability equal to 5% of the Standard Model probability:  $\mathcal{P}(\eta^\pm) = 0.05 \mathcal{P}(0)$ . Mass scale limits  $\Lambda^\pm$ , corresponding the coupling limits  $\eta^\pm$ , for different contact interaction models are presented in Table 1.

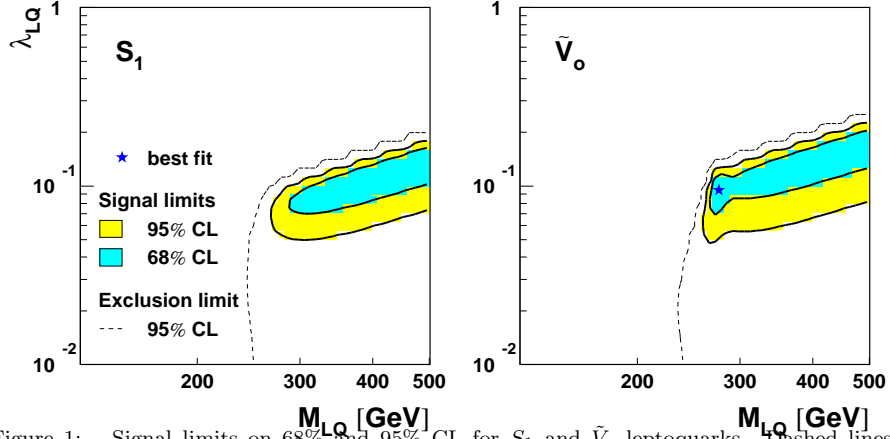


Figure 1: Signal limits on 68% and 95% CL for  $S_1$  and  $\tilde{V}_0$  leptoquarks. Dashed lines indicate the 95% CL exclusion limits. For  $\tilde{V}_0$  model a star indicates the best fit parameters. For  $S_1$  model the best fit is obtained in the contact interaction limit  $M_{LQ} \rightarrow \infty$ .

### 3 Leptoquarks

In a recent paper<sup>5</sup> available data were also used to constrain Yukawa couplings and masses for scalar and vector leptoquarks using the Buchmüller-Rückl-Wyler effective model.<sup>6</sup> In the limit of very high leptoquark masses, constraints on the coupling to the mass ratio were studied using the contact-interaction approximation.<sup>7</sup> The best description of the data is obtained for the  $S_1$  and the  $\tilde{V}_0$  leptoquarks<sup>8</sup> with  $\lambda_{LQ}/M_{LQ} \sim 0.3 \text{ TeV}^{-1}$ . Increase in the global probability corresponds to more than  $3\sigma$  deviation from the Standard Model.

Constraints on the leptoquark couplings and masses were studied also for finite leptoquark masses, with mass effects correctly taken into account. Shown in Figure 1 are the 95% exclusion limits as well as the 68% and 95% CL signal limits for  $S_1$  and  $\tilde{V}_0$  leptoquarks. The best description of the data for the  $\tilde{V}_0$  model is obtained for  $M_{LQ} = 276 \pm 7 \text{ GeV}$  and  $\lambda_{LQ} = 0.095 \pm 0.015$ .

Table 2 summarizes the results of the global leptoquark analysis.<sup>5</sup> For all leptoquark models the 95% CL exclusion limits are given both for  $\lambda_{LQ}/M_{LQ}$  (upper limit) and for  $M_{LQ}$  (lower limit). For models which describe the existing experimental data better than the Standard Model the maximum value of the global probability  $\mathcal{P}_{max}$  and the corresponding coupling to the mass ratio  $(\lambda_{LQ}/M_{LQ})_{max}$  are included. 95% CL signal limits for  $\lambda_{LQ}/M_{LQ}$  and  $M_{LQ}$ , defined by the condition  $\mathcal{P}(\lambda_{LQ}, M_{LQ}) > 0.05 \mathcal{P}_{max}$ , are given for models with  $\mathcal{P}_{max} > 20$ .

Table 2: Results of the global leptoquark analysis: the 95% CL exclusion limits on the leptoquark coupling to the mass ratio  $\lambda_{LQ}/M_{LQ}$  (upper limit) and the leptoquark mass  $M_{LQ}$  (lower limit), the coupling to the mass ratio  $(\lambda_{LQ}/M_{LQ})_{max}$  resulting in the best description of the experimental data and the corresponding model probability  $\mathcal{P}_{max}$ , and the 95% CL signal limits on  $\lambda_{LQ}/M_{LQ}$  and  $M_{LQ}$ , for models with  $\mathcal{P}_{max} > 20$ . Global probability function is defined in such a way that the Standard Model probability  $\mathcal{P}_{SM} \equiv 1$ .

| Model             | 95% CL<br>excl. limits        |          | best description                                 |                     | 95% CL<br>signal limits       |          |
|-------------------|-------------------------------|----------|--|---------------------|-------------------------------|----------|
|                   | $\frac{\lambda_{LQ}}{M_{LQ}}$ | $M_{LQ}$ | $\left(\frac{\lambda_{LQ}}{M_{LQ}}\right)_{max}$ | $\mathcal{P}_{max}$ | $\frac{\lambda_{LQ}}{M_{LQ}}$ | $M_{LQ}$ |
|                   | $TeV^{-1}$                    | $GeV$    | $TeV^{-1}$                                       |                     | $TeV^{-1}$                    | $GeV$    |
| $S_o^L$           | 0.27                          | 213      |  |                     |                               |          |
| $S_o^R$           | 0.25                          | 242      |  |                     |                               |          |
| $\tilde{S}_o$     | 0.28                          | 242      |  |                     |                               |          |
| $S_{1/2}^L$       | 0.29                          | 229      |  |                     |                               |          |
| $S_{1/2}^R$       | 0.49                          | 245      | $0.32 \pm 0.06$                                  | 35.8                | 0.09–0.44                     | 258      |
| $\tilde{S}_{1/2}$ | 0.26                          | 233      |  |                     |                               |          |
| $S_1$             | 0.41                          | 245      | $0.28 \pm 0.04$                                  | 367.                | 0.15–0.36                     | 267      |
| $V_o^L$           | 0.12                          | 230      |  |                     |                               |          |
| $V_o^R$           | 0.44                          | 231      | $0.28 \pm 0.07$                                  | 11.7                |                               |          |
| $\tilde{V}_o$     | 0.52                          | 235      | $0.34 \pm 0.06$                                  | 122.                | 0.16–0.46                     | 259      |
| $V_{1/2}^L$       | 0.47                          | 235      | $0.30 \pm 0.06$                                  | 31.7                | 0.08–0.42                     | 254      |
| $V_{1/2}^R$       | 0.13                          | 262      |  |                     |                               |          |
| $\tilde{V}_{1/2}$ | 0.47                          | 244      | $0.30 \pm 0.07$                                  | 14.8                |                               |          |
| $V_1$             | 0.14                          | 254      |  |                     |                               |          |

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